QUANTITY-DISTANCE CRITERIA
FOR
SMALL NET EXPLOSIVES QUANTITIES

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ABSTRACT

The North Atlantic Treaty Organisation (NATO) document AASTP1, "Safety Principles for the Storage of Military Ammunition and Explosives" does not provide quantity-distance criteria guidance for net explosive quantities (NEQ) less than 5OOkg -sitings are based on a minimum NEQ of 5OOkg. NATO AC258 (Group of Experts on the Safety Aspects of Transportation and Storage of Military Ammunition and Explosives) have held a series of workshops to address this issue. The results of the workshops are presented against the background of the various approaches used by members of the international community.

Current international initiatives in generating test data to support improved modeling of small quantity effects and thus more realistic quantity-distance relationships are discussed. In particular a joint Australia/UK programme of trials to measure the response of brick wall/concrete roof buildings to internal blast loading is described.

INTRODUCTION

1. The current international position regarding advice on quantity-distance (QD) or consequences relating to small net explosives quantities (NEQ) is summarised by the following statement:

> "Storage of NEQ less than 5OOkg needs special consideration and nations requiring advice should contact the Secretary of AC/258."

This is the advice given in AASTP 1, the NATO Storage Manual (Reference 1). Little work has been done to provide a database upon which "the Secretary" could lean to give "special consideration" to a presented problem.

2. The argument has often been put that, because of the great variety of circumstances that need to be considered, any advice on the storage and handling of small quantities must be case specific. Therefore the approach taken currently by NATO is the best that can be envisaged. Whilst it is accepted that there will always be circumstances that "do not fit", generic guidance can and should be given where it is possible to reduce those circumstances to the minimum. Also guidance should be given as to the approach to be taken when special consideration has to be given. This may be in the form of suitable modeling techniques to be used.

3. It was against this background that a workshop was set up by AC/258 (Group of Experts on the Safety Aspects of the Storage and Transport of Military Ammunition and Explosives) with the following objectives:

a. Record national requirements for advice on the storage and handling of small quantities (<=500 kg NEQ) of explosives and ammunition.

b. Collate the presented and other available applicable data.

c. Consider the use of appropriate modeling techniques, eg DISPRE (Reference 4).

d. Identify the level and scope of NATO advice required.

e. Recommend whether the AC/258 Storage Sub-Group should, or are likely to be able to provide the desired level of advice.

4. The storage and handling of small quantities of HD 1.1 explosives and ammunition is immediately seen to be of great importance from the view point of protection from hazard. However, the inadequacy of information for the other hazard divisions can have considerable economic implications even if the potential hazards to life and property are minimal. For example, in UK, air crew flying clothing carries emergency pyrotechnics such as flares. As some of these are classified HD 1.3 explosives items, they should be treated in accordance with the storage rules. The default public traffic route or inhabited building quantity-distance for small quantities of HD 1.3 is 25 m. Clearly the hazard from the clothing with the flares will be little different than that if they were not present. Whilst in this case common sense prevails and effective zero QDs are used, this is not in accordance with the prescriptions. Strict adherence to the prescriptions would have significant effect on the economic use of airfield accommodation. Thus, in considering small quantities it is important that prescriptions relating to the storage and handling of all hazard divisions are reviewed.

5. In the paragraphs below the approaches currently taken by NATO, Australian, UK and US authorities and the outcome of the three meetings of the AC/258 Small Quantities Workshop are discussed. Planned joint Australian/UK trials and a program of precursor UK trials which have recently commenced are described.

NATO ADVICE ON PROTECTION AGAINST THE EFFECTS OF SMALL QUANTITY EVENTS.

6. The current approach taken by NATO is that mentioned in Para 1. The reliance on "expert" advice leads to the danger of widely varying standards being set dependant on the "expert" advice sought. Clearly the wider the range of advice available, the greater will be the likelihood and diversity of advice that may be given. Thus internationally it is almost certain that standards of handling and storage of small quantities set in this way will vary considerably. The only common feature may be in that default conditions will be those set for 500 kg NEQ or fixed distances related to fragment or debris hazard.

AUSTRALIAN ADVICE ON PROTECTION AGAINST THE EFFECTS OF SMALL QUANTITY EVENTS

7. The current Australian approach permits the use of reduced QD when it can be shown by test or analysis that the reduction may be made without imposing hazards at the exposed site greater than those accepted as tolerable.

8. The following factors must be considered before a QD less than that applicable for 50 kg NEQ (as extrapolated downwards from the NATO formulae) is applied:

a. **Projections.** Projections include fragments and lobbed ammunition, debris from the building structure, earth cover and crater. In some cases, a smaller NEQ will make little difference to the NATO requirement to apply a fixed minimum distance to provide protection from fragment damage. However where NEQ are small and there is no designed fragment capability, there will be little or no projection hazard and the fixed minimum distances can be substantially reduced. It is not necessary that all projections are contained, but the hazard must not exceed the tolerable level. It is not possible to provide tabular distances for projection. Each case must be assessed individually by the licensing authority.

b. **Blast.** The NATO distance function formulae for HD 1.1 may be used to estimate OD protection from blast for any NEQ. As the NEQ becomes smaller, a greater proportion of the blast energy is absorbed by the building and for quantities of a few kilograms, the blast damage outside the building environs may not be significant. Special care is needed to avoid enhanced effects due to blast focusing as distances are reduced.

c. **Thermal and Ground Vibration Effects.**The NATO QD functions for HD 1.3 are used for determining thermal protection requirements. These may be extrapolated below 50 kg if sufficient protection is provided against radiant heat and firebrands. Damage to an exposed site due to ground shock is unlikely to be a critical factor when considering NEQs up to 50 kg at a potential explosion site.

UK ADVICE ON PROTECTION AGAINST THE EFFECTS OF SMALL QUANTITIES

9. The advice on the conditions for handling and storage of explosives in UK is promulgated in a series of leaflets published by the UK Explosives Storage and Transport Committee (ESTC). In particular ESTC Leaflet 5 Part 2 details the QDs for the separation of storage and process buildings from one another and from public traffic routes (PTR) and other inhabited buildings (IBD). As regards advice on the siting of buildings containing small quantities of explosives, it is little better than that given in the NATO storage manual. Although the QD tables give distances for quantities down to 50 kg, only in specific cases, such as HD 1.1 substances in frangible buildings, can the distances below those for 500kg be used. For most cases default distances, eg 270 or 400 m IBD for HD 1.1 or 60 m IBD for HD 1.3 in light buildings, are recommended.

10. For NEQ below 50 kg, the advice given is

"Distances for quantities below 50 kg are more dependant on site specific factors such as building construction, types of explosive, construction and protection at exposed

> sites, etc and it is not practical to give general rules for such quantities. The interpretation of such situations is therefore left to the judgement of Departmental Chief Inspectors of Explosives in consultation with the appropriate technical experts"

Even within the national sphere this too can lead to the setting of different standards between individual departments.

11. The UK Army licensing authority licence many of their small quantity locations under "Delegated 25 kg" licences. To comply with these licences only specified natures of ammunition packaged in their full service packaging can be stored in suitably secure rooms where the electrical installations comply with strict standards. Typically, small quantities of pyrotechnic (smoke producing, illuminating, lachrymatory etc) ammunition are stored in this way. Further delegated licences are issued for garages housing EOD vehicles to enable their specialist explosives to be stored ready for use. Unitization of risk to less than 5 kg is a condition of these licences. The positioning of such garages is carefully controlled to minimise risk to personnel outside the building. Similar arrangements are made by the other Services for the handling and storage of small quantities. Of importance to the Services is the validation of the approaches they have taken to address these small quantity issues.

US ADVICE ON PROTECTION AGAINST THE EFFECTS OF SMALL QUANTITIES

12. For HD 1.1 explosives the US Department of Defence Explosives Safety Board (DDESB) has set default distances of 670 ft (205 m) for NEQ< = 100 lb (45 kg) of demolition explosives, thin cased or low fragmentation ammunition items, bulk high explosives, pyrotechnics and in-process explosives and 1250 ft (381 m) for NEQ>100 lb. Deviation from these defaults can only be made by satisfying DDESB by means of supporting evidence that, for the specific circumstances under consideration, lower distances will still provide acceptable levels of risk. This may be achieved by reduction of maximum credible event (unitization) or amelioration of potential consequences, for example reduction in fragment throw by the use of barricades. Trials evidence is an important part of such supporting evidence. An example of such a submission is given at Annex A.

13. Currently testing methods are being developed to allow for more generic testing and a tri-service database is being set up as a means of collating and standardising test information.

14. As an alternative way of producing generic storage conditions for small quantities, a fully containing storage concept is under development (The Miniature Magazine). The objective is to produce a magazine design in which there is a minimal and acceptable external effect in the event of the initiation of the contents. If this is successful, a small fixed distance will be allocated ~o HD 1. 1 explosives below a specified NEQ stored in the Miniature Magazine.

15. Limited quantities of items in HD 1.2 (with 400 ft (121 m) Inhabited Building Distance), HD 1.3 and HD 1.4, for reasons of operational necessity, may be stored in facilities such as hangers, arms rooms, troop buildings and manufacturing or operating buildings without regard to quantity-

distances. Fragmentation shielding will be provided for HD 1.2. Examples include: HD 1.2 - small destructors, fuses, firing devices and 40 mm grenades; HD 1.3 - document destroyers, riot control munitions; and HD 1.4 - small arms ammunition and riot control munitions.

THE NATO AC/258 SMALL QUANTITIES WORKSHOPS

16. Representatives from nine NATO nations attended all or some of the three NATO AC/258 Small Quantities Workshops held between February 1993 and March 1994. In addition, after the first Workshop, Australia expressed an interest in the small quantities issue and presented a paper at the second Workshop in October 1993 describing a program of tests that they were planning to study the effects from small (10 kg to 50 kg) HD 1.1 explosions in buildings.

17. At the first meeting the national representatives made statements of the approach currently adopted in their countries and of their specific areas of interest within the small quantities issue. Whilst most use the fixed fragment related distances described above in one form or another, they are sometimes supplemented by additional advice. For example, blast related QDs from the NATO tables are extrapolated to lower NEQs and applied as waivers. Spain is also developing multiple chamber facilities for storing unitised NEQs of 100 kg with the aim of containing consequences within a range of 110 m.

18. All the national representatives present saw a need for improved information on the effects of small quantities in order that more rational and standardised approaches could be made to their conditions of handling and storage.

19. Agreement was reached that the first step in considering the problem should be the generation of an international database on the subject. Only in this way could the current state of knowledge be identified. As a result a first collation of data from the NATO members was presented at the second meeting of the Workshop. Much of the information was drawn from a survey of the DDESB Explosives Safety Seminar Proceedings and was supplemented by information supplied by the other attending nations. Further refinement and extension of the database is still being carried out.

20. Discussion of the information known to exist for "strong" structures such as Hardened Aircraft Shelters and Igloos led the participants to the conclusion that QDs could be developed for NEQs below 500 kg and limiting conditions identified below which there would be minimal external effects. These conditions might vary between sides of the structure concerned, for example, breach of the front of an igloo and consequent debris throw will be different from that to be expected to the sides and rear. At the third meeting, Danish proposals (Reference 2) were tabled offering relationships for different levels of effect:

> I. **Very Small NEQ:** The NEQ is so small in relation to magazine volume that no significant structural damage would occur and doors would remain in place in case of an explosion. The NEQ in this case is likely to be of the order of 5-8 kg depending on loading density, structure and position of the charge.

ii. **Small NEQ:** In this case, the doors will be damaged and opened or even thrown off their hinges and fragments and debris will be propagated through the door openings to a limited distance. The magazine structure may be severely damaged but no debris will be thrown out. This may be the case for NEQ up to approximately 20 kg depending on loading density, structure and position of the charge.

Safety precautions can be limited to a safety sector and safety range on the door side.

iii. **Medium Size NEQ:** In this case, the doors will be damaged and fragments and debris will be propagated through the door openings in a sector on the door side out to a defined distance. The magazine structure will be severely damaged and the roof may collapse after the explosion but still no debris from the concrete structure will be thrown out. This may occur for NEQ up to approximately 100 kg.

Safety precautions can be limited to a safety sector and a safety range on the door side to accommodate fragments and debris and a safety radius around the magazine to avoid damage to personnel caused by the shock wave overpressure. (eg D12 = $22.2Q^{1/3}$ for 100 kg = 100 m)

iv. **Larger Size NEQ:** This case is similar to the above mentioned for "medium size NEQ" except for an increasing amount of the concrete structure of the magazine (especially the roof) being thrown out as debris.

Safety precautions can be limited to a safety sector and safety range on the door side as mentioned above and a safety radius to accommodate debris throw around the magazine. For the low loading densities (NEQ<500 kg) calculations may show that these distances are within the shock wave overpressure range (eg D12).

21. The US (Reference 3) have since proposed QDs related to the four categories for US Third Generation HAS and Earth-Covered Magazines. These are based on available trials data and are currently under discussion within the NATO AC258 Group. Their values are shown in Table 1 (Table 3 of Reference 3). Additional details of this proposal are presented at Reference 6.

TABLE 1 RECOMMENDED SMALL NEQ QUANTITY-DISTANCE

US THIRD GENERATION HAS (NOMINAL VOLUME = 5,200M^3)

CATEGORY	NEQ (kg)	US			NATO		
		FRONT	SIDE	REAR	FRONT	SIDE	REAR
1. VERY SMALL	0-2	0	0	0	0	0	0
2. SMALL	2-50	80	8	2	80	12	3
3. MEDIUM	50-100	80	10	5	80	15	8
4. LARGE	100-500	80	$17Q^{1/3}$	$6Q^{1/3}$	80	$17Q^{1/3}$	$8.4Q^{1/3}$

EARTH-COVERED MAGAZINE (NOMINAL VOLUME = 490M^3)

CATEGORY	NEQ (kg)	US			NATO		
		FRONT	SIDE	REAR	FRONT	SIDE	REAR
1. VERY SMALL							
2. SMALL	0-50	$42Q^{1/3}$	50	50	$42Q^{1/3}$	50	50
3. MEDIUM	50-100	$42Q^{1/3}$	76	76	$42Q^{1/3}$	76	76
4. LARGE	100-200	$50Q^{1/3}$**	$17Q^{1/3}$	$20Q^{1/3}$	$50Q^{1/3}$**	$17Q^{1/3}$	$20Q^{1/3}$

**Maximum range is 381m

NOTE ALL RANGES ARE IN METERS

TABLE 1 RECOMMENDED SMALL NEQ QUANTITY-DISTANCE

22. For other structures, for example, above-ground storehouses or process buildings, the response would be sensitive to the structure design and materials, the position and geometry of the charge etc. In these cases it was thought that generic solutions may not be so easily generated and that individual assessment using consequence modelling may be the better way forward. In this case, the importance would lie in the development of well validated models, particularly of building debris projection. It was agreed that work currently being undertaken at Southwest Research Institute on behalf of the Klotz Club (see the paper by P Bowles (Reference 5) presented at the current 26th Explosives Safety Seminar) to develop computer models would be monitored.

23. Ameliorative techniques such as unitization and use of earth cover for the reduction of fragment hazard were also considered of importance. Much work has been carried out over recent years, in particular, on effective barriers between stacks of munitions, and such techniques can be used to great advantage.

24. Whilst the UK and Australia showed particular concern at the lack of available information on the effects of very small quantities (<50 kg), other nations did not consider it of high priority. It was agreed therefore that any work in that area would be sponsored by the nations interested. The programs proposed by Australia and UK are described below.

THE FUTURE PROGRAMME FOR THE GENERATION OF QUANTITY DISTANCE AND CONSEQUENCE MODELLING DATA FOR SMALL QUANTITIES OF EXPLOSIVES.

Hazard Division 1.1

25. As has been stated above, the international data relating to small quantities effects is currently being collated and analyzed. It has already been concluded that there are sufficient data available on the effects of quantities in excess of around 100 kg in strong structures (Igloos and Hardened Aircraft Shelters) to develop extensions to the existing Q-D tables based on fragment/debris throw (Reference 3). At lower NEQs the evidence suggests that there will be little external effect from an explosion in such structures. Further analysis of the available data must be completed before firm recommendations for extension of QDs can be made and some trials may be necessary to determine the break point between quantity defined distances and the fixed distances that will result from full containment by the structure.

26. For NEQs of a few tens of kilograms or less in "normal" structures, eg process buildings, EOD stores etc., case-by-case assessment using consequence analysis tools appears to be the most potentially productive way forward. The major hazard in these circumstances will come from the projection of either primary fragments or debris from the containing structure. Southwest Research Institute, San Antonio, Texas have developed a suite of computer programmes, DISPRE (Reference 4), to predict the distribution of building debris as the result of an internal explosion. Explosion shock and quasi-static impulses on the walls of the building or room are calculated and summated. The debris throw (mass, velocity, range, energy) are then predicted using a Monte Carlo technique. The correlations between debris throw parameters and impulse on the walls are empirically determined from trials results. At the moment the applicability of the model is limited by the extent of the trials database to an NEQ of 250 lb (114 kg) or less and three building materials (reinforced concrete, hollow tile blocks and hollow concrete blocks). Whilst the suite of programmes is attractive in its approach to the prediction of debris throw, to be of more universal value, it will be necessary to extend the database and hence the range of applicability of DISPRE.

27. As a first step in extending DISPRE's applicability, UK have commenced a programme of trials to investigate the debris throw from brick walls. The programme will concentrate on situations in which the volume of the charge is small relative to the volume of the structure and it is placed near to one wall. Thus debris throw will only be expected from the one wall, though collapse of the rest of the building may occur. Although there may be circumstances in which much higher loading densities are achieved and projection of debris from all faces of the might be expected, UK consider that the lower loading density situation will be the more common. The effects of charge size and proximity to the wall, wall construction and venting

of the structure (doors, windows, frangible panels etc) will be tested. Pressure on the walls of the structure, initial velocity of fragments, their trajectories, roll and ricochet along with ground pick-up and debris mass and dimensions are being measured.

28. To date two firings have taken place; 25 kg, 1 m from a free-standing brick wall and 10 kg, 1 m from the brick wall of a 3 m cube cubicle. Records from the trials are still being analyzed and should provide a considerable amount of data on initial velocity, break-up and roll and ricochet. In the first test (25 kg) the wall was completely destroyed and brick debris dispersed over about a +/- 300 arc out to 50 m, the debris density falling very rapidly beyond 30 m. The second emphasised the power of the quasistatic pressure in the cubicle. There was little debris within 25m of the position of the cubicle. As video records show, the almost intact wall passed over that distance before breaking up. Debris was densest (almost a complete carpet) at 40-60 m and then dropped in density to beyond 100 m. It is estimated that the 25 mm steel roof was blown some 20 m into the air.

29. Further tests will be carried out in cubicles with concrete roofs in order that roof response can be measured. Charge weights between 2 and 20 kg at differing standoffs will be used.

30. An important objective of the UK tests was to develop the instrumentation and imaging techniques to enable the maximum amount of numeric information to be derived from the tests on such aspects as roll and ricochet and initial velocities. This was to be done prior to the proposed trials in Australia described below in order that there was the maximum confidence that the best could be gained from these expensive tests.

31. Tests are due to commence at Woomera, South Australia in 1995 to determine the consequences of the detonation of charges from 10 to 50 kg TNT equivalent in brick wall concrete roof structures. Details of the proposed program are given at Annex B. In the event, the tests will extend the work being carried out in UK to higher NEQ. They will also test the effects of simple traverses in reducing debris throw and the effects of larger vent areas (doors, windows etc) on the severity of the effects. Details of camera position, type etc have awaited the outcome of the UK tests and final test layouts will be agreed shortly.

Hazard Division 1.2

32. For the past two years, US DDESB and UK ESTC, under NATO AC/258 auspices, have been carrying out a programme of work to determine the effects from exposed stacks of HD 1.2 ammunition and the results of this work are presented in another paper at this Symposium. Although tests have so far focused only on the 105 mm M1 Cartridge, indications are that hazard distances can be related to numbers of rounds in the stack down to very small numbers - the lowest number tested was 30 (NEQ 135 lb). The programme for the near future is to concentrate on extending the database to smaller calibers, different packaging and different explosive fill.

33. Quite clearly the introduction of a structure around the stack of ammunition will alter significantly the spread of debris from such an event. If the stack is contained within a strong structure such as an igloo then the external effect is expected to be negligible. This thesis is

soon to be tested in Australia in SPANTECH igloos using stacks of 105mm ammunition. The US also intend to test the ability of their Miniature Magazine to withstand the erosive effects of the many small explosions from a stack of HD 1.2 ammunition.

34. Due to insufficient funding there is, currently, little work planned on the investigation of the effects of less strong structures on HD 1.2 events within them. A possible way forward may be the determination of the effect of single events, eg the effect of one 105mm shell exploding, and then a structural analysis of a number of such events. Projection of debris may be included by multiplying that predicted for the one round using the DISPRE technique. Using this approach it may be possible to define by calibre and numbers of rounds or NEQ circumstances within which fixed or minimal distances can be applied.

Hazard Division 1.3

35. The HD 1.3 thermal radiation hazard is quantified in terms of the effects of the flux from burning exposed propellant where the whole mass can ignite within a few seconds. In most cases, HD 1.3 munitions will catch fire spasmodically over a prolonged period and the thermal radiation flux will be considerably lower than that from the equivalent bulk propellant NEQ. Given the length of the event and the consequent opportunity for personnel evacuation before it has developed, for low NEQs there is a strong argument for minimal hazard distances. In many situations in which small quantities of HD 1.3 explosives are stored, zero quantity distances are assumed, it is suggested, on the basis that any event would be little worse than a fire not involving HD 1.3 materials. In the assessment of potential consequences from a HD 1.3 event it is important that the size of the event is firmly identified. As an example, if flare packs are stored in steel boxes, in steel cupboards; then it is important to identify the unit risk - is it the few flares in the steel box, all in a steel cupboard or all those in all the steel cupboards. Once this is identified then sensible judgements can be made on any separation or hazard distances that should be applied. Thus the approach suggested is one of a caseby-case assessment where it may be necessary to carry out elementary tests to determine the potential consequences of an event.

CONCLUSIONS

36. Over recent years the need to examine the problems of storing or handling small quantities of explosives of all hazard divisions has become increasingly important not only from the explosives safety point of view but also from that of economics in land and facilities usage. Between 1993 and 1994 the NATO AC/258 Storage Sub-Group held a series of Workshops with the aim of identifying international problem areas in the handling and storage of small quantities and putting forward proposals for programmes of work to set up a framework of rules for their resolution. A database of existing information has been set up, areas of specific concern, eg hardened structures, have been identified and possible ways forward have been proposed. This international effort is to be supplemented by national programmes, and work to be undertaken in UK, USA and Australia has been described.

37. The lower HD 1.1 NEQ issues will be addressed by the development of consequence models, in

particular, identifying the effects of debris throw. SWRI's DISPRE suite of computer programmes have been developed to address the problem on a limited front and its applicability is to be extended by broadening the database upon which it is set.

38. Case-specific solutions based on well founded understanding of unit risks may be the best way of validating existing lower hazard division situations or assessing new ones.

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1. Allied Ammunition Storage and Transport Publication (AASTP1), Edition No 1; Manual of NATO Safety Principles for the Storage of Military Ammunition and Explosives; May 1992.

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3. Small NEQ Quantity-Distance; US(ST) IWP/105-94; Michael M Swisdak; 9 March 1994.

4. Building Debris Hazard Prediction Model, Final Report for SwRI Project 06-2945, prepared for Bernard Johnson Incorporated under Mason & Hanger - Silas Mason Co Inc Contract H0760103; US Government Contract DE-AC04-76DP-00487; Bowles P M, Oswald C J, Vargas L M and Baker W E; November 1990.

5. Earth-Covered Ammunition Storage Magazines Quantity-Distance Model DISPRE2; P Moseley-Bowles; 26th Explosives Safety Seminar, Miami, Fl; August 1994.

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ANNEX A

US APPROACH TO REDUCED Q-DS FOR SMALL NET EXPLOSIVES

QUANTITIES BASED ON TESTS AND/OR ANALYSES - EXAMPLES

DoD POLICY

Al. The US Department of Defense (DoD) policy that establishes uniform explosives safety standards is promulgated in DoD 6055.9-STD, DoD Ammunition and Explosives Safety Standards. These standards are applicable to DoD-titled ammunition and explosives (A&E), to associated personnel and property exposed to the potential damaging effects of an accident involving A&E during their development, manufacturing, testing, transportation, handling, storage, maintenance, demilitarisation and disposal. Tests and/or analyses approved by the Department of Defense Explosives Safety Board (DDESB), may be used to support deviations from these standards, such as reduced quantity-distance (QD) criteria for small net explosives quantities (NEQ).

DISPRE MODEL

A2. For NEQ up to and including 114 kg (250 lb) inside buildings constructed of selected materials, the DDESB has approved a method of analysis (model) for determining reduced Q-D criteria based on the building debris hazards. It should be pointed out, however, that the hazards from primary fragments, if present, need to be addressed separately. Otherwise, the default minimum fragment/debris distances discussed in paragraph 10 of the main text of the paper apply. This model, DISPRE (Dispersion Prediction), is documented in DDESB Technical Paper 13 "Prediction of Building Debris for Quantity-Distance Siting" April 1991. A recent description of the application of DISPRE was presented at the 25th Explosives Safety Seminar sponsored by DDESB in August 1992 entitled: "Practical Use of the Building Debris Hazard Prediction Model, DISPRE" by P Bowles. Extension of this work is discussed in Reference 5 of this paper.

CONEX TRIALS

A3. An example of a DDESB approved Q-D reduction based on the results and analysis of trials is provided by the US Army Project Manager, Ammunition Logistics, Quickload Program (now Safeload Program) Technical Data Package (TDP) "Storage of Mixed Munitions in CONEX Containers" by W Lawrence and R Frey dated 25 November 1991. The test results supporting the TDP are documented in US Army Ballistic Laboratory (now Army Research Laboratory) Technical Report BRL-TR-3203 "Fragment Hazards from Munitions in Containers" byWLawrencedatedFebruary1991.1

A4. The test program consisted of eleven tests to identify debris, fragments and airblast hazards associated with the detonation of selected A&E in CONEXes (container express). The NEQ for the tests ranged from 18 lb (8.2 kg) to 500 lb (227 kg). Five tests were conducted with acceptor CONEXes with and without sand bag barricades on three sides and roofs of the CONEXes. Also tests were conducted with and without sand bag barricades outside the front door. Active instrumentation included airblast transducers and video coverage with pre/post shot photography. Passive measurements included 360 degree fragment recovery areas out to 600/1200 ft (180/365 m) (according to the charge size) and Bikini (blast) gauges. Post-test observations included measuring the crater dimensions, evaluating the quantity of unreacted ammunition and fragment recovery/evaluation.

A5. The following conclusions were derived from the tests:
(Technical Report BRL-TR-3203)

a. Detonation of tested A&E in one CONEX does not propagate to an adjacent CONEX at a separation distance of 8 ft (2.4 m).

b. Sand bagging the donor and acceptor CONEXes prevents extensive damage to the acceptor CONEX from a donor detonation. However, sand bagging is not necessary to prevent propagation.

c. Sand bagging the CONEXes decreases the hazardous fragment areal number densities at distances evaluated beyond 300 ft (90 m); however, sand bagging increases cook-off and the burning rates of the A&E and other debris close to ground zero.

A6. Based on the test results and analysis, the CONEX TDP provides an approved method for storing certain mixed A&E in a CONEX with reduced Q-D criteria.

a. The TDP applies to the following A&E up to a maximum NEQ of 500 lb (227 kg):

(1) HD 1.1 bulk high explosives (HE) and demolition charges

(2) CTG, Cal .45 ball, 50 cal (all types), 5.56 mm ball (all types). 7.62 mm ball (all types)

(3) Grenade, smoke (all types)

(4) File Destroyer M4

(5) Signal Illum ground (all types)

b. Application of this TDP reduces intermagazine spacing to 8 ft (2.4 m). Sandbagging and front door barricade are not required. The normal (default) required spacing is 96 ft (29 m)

c. Application of this TDP reduces the Inhabited Building Distance (IBD) to 360 ft (110 m). Normal (default) IBD is 1250 ft (381 m).

A7. A drawback to this (trials) approach is that the TDP only applies to specific A&E in certain configurations. Storage of other munitions nullifies the Q-D reduction unless applicability can be supported by additional tests and/or analyses.

ANNEX B

PROPOSED SMALL QUANTITY TRIALS TO TAKE PLACE AT WOOMERA, SOUTH AUSTRALIA

INTRODUCTION

B1. In early 1993, representatives of the Australian Department of Defence and the United Kingdom Ministry of Defence met in Canberra to consider future joint AS/UK explosives effects trials following completion of the recent series of successful large scale STACK FRAGMENTATION trials at Woomera South Australia.

B2. It was recognised that further trials were needed to obtain additional large magazine data and also to obtain data on the explosion effects characteristics of explosions in small quantity explosives storehouses (ESH) ie ESH holding 50 kg TNT equivalent net explosive quantity (NEQ) or less. A series of six small quantity trials was proposed.

B3. A trials outline was forwarded to the UK in September 1993 for NATO AC/258 Small Quantities Workshop consideration. Further refinement of the trials plan occurred during the visit of UK ESTC representatives to Australia in October and November 1993 and the consideration of written comments from the UK that arrived in January 1994. The consequence of these reviews was that twelve tests are now proposed, ten "joint" and two "special to UK". A formal request for trial was submitted and this subsequently has been accepted by the Australian DoD Directorate of Trials as DEF TRIAL 8/626.

AIM

B4. The aim of the trial is to determine the effects of a detonation of up to 50 kg NEQ HD 1.1 explosive in a small quantity ESH.

LIMITATIONS

B5. The following limitations were imposed on planning:

a. four brick ESH building types to meet joint AS/UK requirements were specified:

(i) English bond solid brick (EBSB) single bay with frangible roof (FR).

(ii) Double brick cavity spaced (DBCS) single bay with FR.

(iii) EBSB single bay with heavy reinforced concrete roof (RCR).

(iv) DBCS single bay with RCR.

b. In addition a low cost brick ESH of UK design with concrete roof and reinforced concrete column enhancement (in accordance with UK DWS specification D/DWS 27/42/1/3 dated 5 Jan 1994) was to be tested under separate funding arrangements initiated by the UK.

c. Three NEQs were specified:

(i) 10 kg NEQ TNT equivalent,

(ii) 25 kg NEQ TNT equivalent,

(iii) 50 kg NEQ TNT equivalent.

TRIAL OUTLINE

B6. Twelve small quantity brick ESH of a type typical of small unit magazines are to be constructed. The buildings will be a mixture of single cell EBSB or DBCS magazines with light frangible or heavy reinforced concrete roofs and special UK design magazines. A 10 kg, 25 kg or 50 kg TNT explosive charge will be detonated inside each ESH. The ESH experiencing the 25 kg or 50 kg detonations will be traversed on two sides only to enable comparisons of fragmentation trajectories. The matrix at Table 1 defines the ESH by type of design and explosives loading.

TABLE B1 PROPOSED JOINT AS/UK SMALL QUANTITY ESH FRAGMENTATION TRAILS

SERIAL	BUILDINGS/COMMENT	NEQ (kg)
1.	DBCS frangible roofed ESH untraversed, charge to be centrally located.	10kg HD 1.1 (non-fragmenting) (nf)
2.	DBCS frangible roofed ESH untraversed, charge to be located 1.0 m above floor and 0.5 m from wall opposite door.	10 kg HD 1.1 (nf)
3.	EBSB frangible roof - semi traversed	25 kg HD 1.1 (nf)
4.	DBCS frangible roof - semi traversed	25 kg HD 1.1 (nf)
5.	As for serial 3	50 kg HD 1.1 (nf)
6.	As for serial 4	50 kg HD 1.1 (nf)
7.	EBSB reinforced concrete roof - semi traversed	25 kg HD 1.1 (nf)
8.	DBCS reinforced concrete roof - semi traversed	25 kg HD 1.1 (nf)
9.	As for serial 7	50 kg HD 1.1 (nf)
10.	As for serial 8	50 kg HD 1.1 (nf)
11.	RC Column Heavy Roof - semi traversed	25 kg HD 1.1 (nf)
12.	RC Column Heavy Roof - semi traversed	50 kg HD 1.1 (nf)

TABLE B1 PROPOSED JOINT AS/UK SMALL QUANTITY ESH FRAGMENTATION TRIALS

OBJECTIVES

B7. The trial objectives are to obtain the following data:

a. The dispersion of fragmentation and the derivation of fragment energy density contours.

b. The fragmentation containing effects of traverses - 25 kg and 50 kg detonations.

c. Overpressure vs time measurements as detailed in Appendix Il.

d. High speed cine cover of:

(i) side and rear wall movement,

(ii) ESH roof movement,

(iii) fragment projection and fragment velocities in the near and extended fields in order that full trajectories for as many fragments as possible can be derived,

(iv) fragmentation roll and bounce.

GENERAL ESH DESIGN CRITERIA

B8. Test building construction is to be based on the Army magazine design drawings at Figures B1 and B2 and the UK design at Figure B3, with design and construction detail as specified in the following paragraphs. To simplify instrumentation and trial site preparation, and if feasible, the magazines may be pre-constructed on reinforced concrete slabs and trucked to the trial site as required for test.

B9. Internal dimensions: 3 x 3 x 2.4 m (L x W x H)

B10. Wall types:

a. EBSB construction of 230 mm thickness where specified

b. DBCS construction of 270 mm thickness where specified

c. Bricks used for the EBSB are to be a different colour to those used for the DBCS construction.

d. Construction details are given at Appendix

B11. Floors: Floors are to be 150 mm RC cast in situ with integral footings, reinforced top and bottom with F82 mesh. There is to be a 10 day curing time before erecting brickwork. Increased thicknesses and reinforcing may be required if transportable, pre-constructed magazines are used.

B12. Roofs:

a. Frangible: Fibro cement single pitch on 75 x 38 battens ~ 900 centre line.

b. Heavy RC: Cast in situ 150 mm concrete reinforced top and bottom. Cure time 28 days.

B13. Doors: Centrally located on the front of each building. A 50 mm solid wood core door with a security layer of 1.6 mm steel sheet on the external face is to be constructed. Normal hinges and bolt closures are to be fitted.

B14. Fittings: Amplimesh security mesh is to be fitted inside the frangible roof buildings at ceiling level. Metal conduit representing electric reticulation conduit is to be fitted to replicate a typical lighting wiring configuration. No shelves, windows or skylights are to be fitted.

B15. Traverses: A double earth slope traverse (to UK ESTC Leaflet 6 prescriptions) level with the ESH eaves is to be constructed for the 25 kg and 50 kg NEQ ESH trials (ie 10 kg NEQ trial ESH are not to be traversed). The ESH are to be traversed at the back and left walls. The doors are not to be shielded by traverses. As the trials are unlikely to cause major damage to the traverses, only one set of traverses needs construction. Some refurbishment may be necessary after each firing.

EXPLOSIVE TYPE, PLACEMENT AND INITIATION

B1 6. Ten, 25 kg and 50 kg encased or lightly cased TNT or TNT equivalent charges, assembled from 5 kg blocks, with a density greater than 1.5 Mgm~^{3} are to be prepared for the trials. Single point initiation using an EBW (exploding bridgewire) detonator is required. Imaging equipment "run-up" and instrumentation time zero requirements are to be incorporated into the charge firing circuitry. For the 25 kg and 50 kg firings the charge will be placed 1 m above the floor in the centre of the ESH. For the 10 kg NEQ tests, the charges will be placed centrally, 600mm from the rear wall and 1 m above the floor.

INSTRUMENTATION REQUIREMENTS

B17. Gauges: Pressure gauges to measure the pressure/time and impulse experienced by the walls are to be positioned in accordance with Appendix II. The calculated peak pressures, impulses and pressure pulse lengths will be provided separately. It is anticipated that gauges in the test ESH may be damaged beyond repair.

B18. High Speed Imaging: High speed imaging cameras (either cine or video) will be required for each firing to obtain the data requirements at para 7.e. Details are given at Appendix Ill.

FRAGMENTATION SEARCH AND ASSESSMENT

B19. A full fragmentation search pattern extending outward from the blast epicentre is required to ranges where no further brick, concrete etc debris is visible is required. A 3600 polar survey extending to 300m centred on the GZ (centre of the test ESH) is to be conducted. 100 sectors with 20 m long segments are to be surveyed and peg marked. Brick and concrete debris of size greater than 50 mm in any dimension is to be recorded. Metal debris of any size is to be recorded. In the inner 20 m radius circle a search is to be made in one of the four quadrants only (an untraversed one) to ascertain the total mass of concrete and brick debris above 50 mm in any dimension.

SITE LOCATION

B20. A clear, level site for the trial is to be selected. The site is to be free of debris and undergrowth to simplify fragment collection and subsequent site cleanup.

FIGURES

B1. Single Bay ESH, Frangible Roof.

B2. Single Bay ESH, Heavy Reinforced Concrete Roof.

B3. UK ESH with RC Columns.

APPENDICES

I. Magazine Construction Details

II. Pressure Measurement Details

III. High Speed Imaging Details

FIG B1 - SINGLE COMPARTMENT FRANGIBLE ROOF

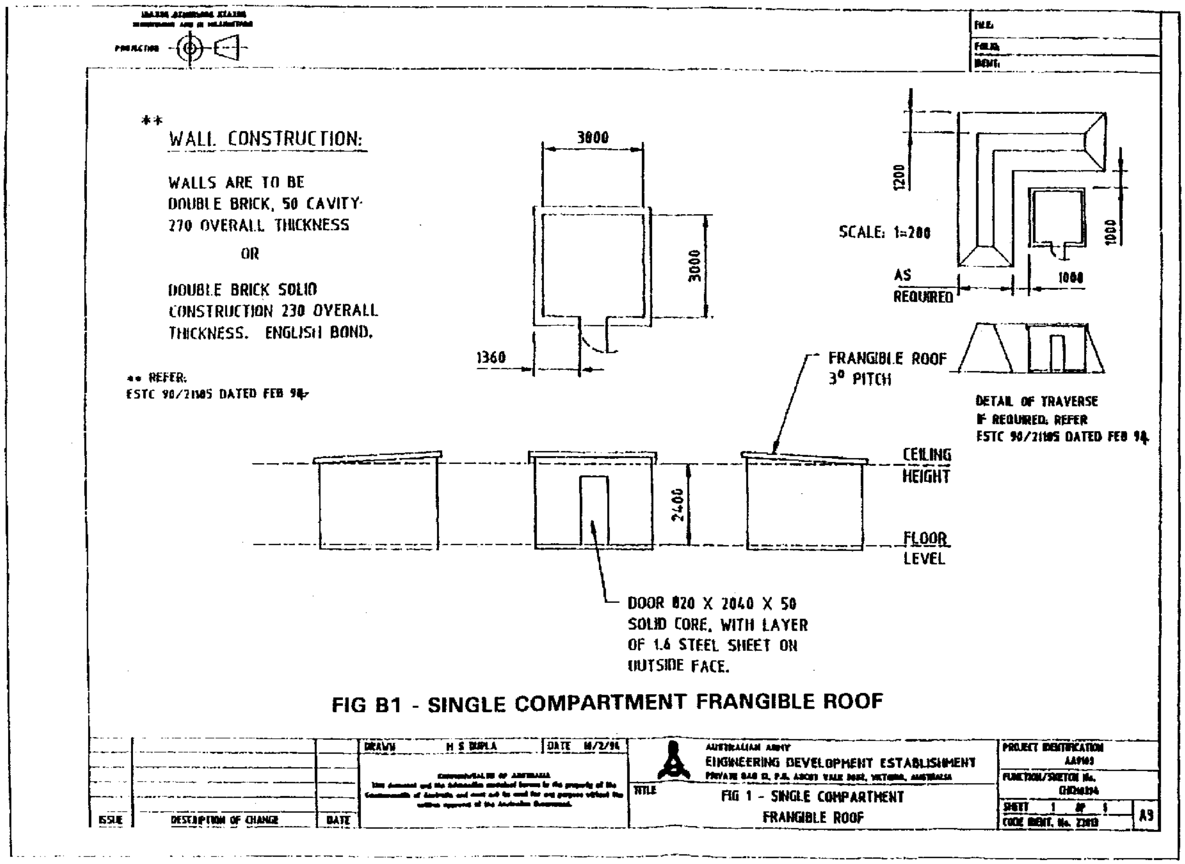

FIG B2 - SINGLE COMPARTMENT HEAVY RC ROOF

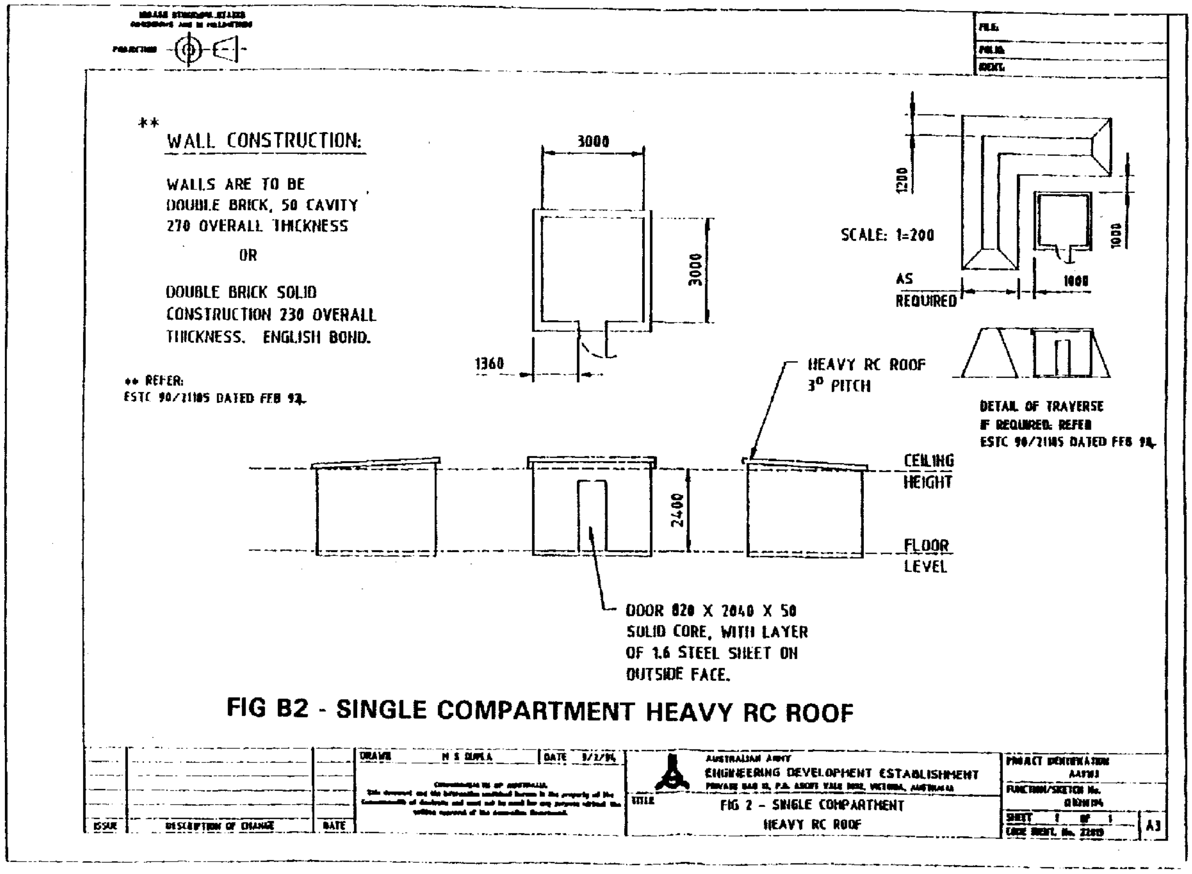

FIGURE B3 - ESH WITH RC COLUMNS

NOTES

1. GROUND SLAB THICKENING/FOUNDATIONS, TO SUIT GROUND CONDITIONS.
2. R.C. COLUMNS TO BE MOUNTED AT 5M CENTRES MAXIMUM, AND AT ALL CORNERS.
3. CONCRETE GRADE C35 MINIMUM.
4. REINFORCEMENT- MAIN AND SECONDARY- HOT ROLLED HIGH YIELD.

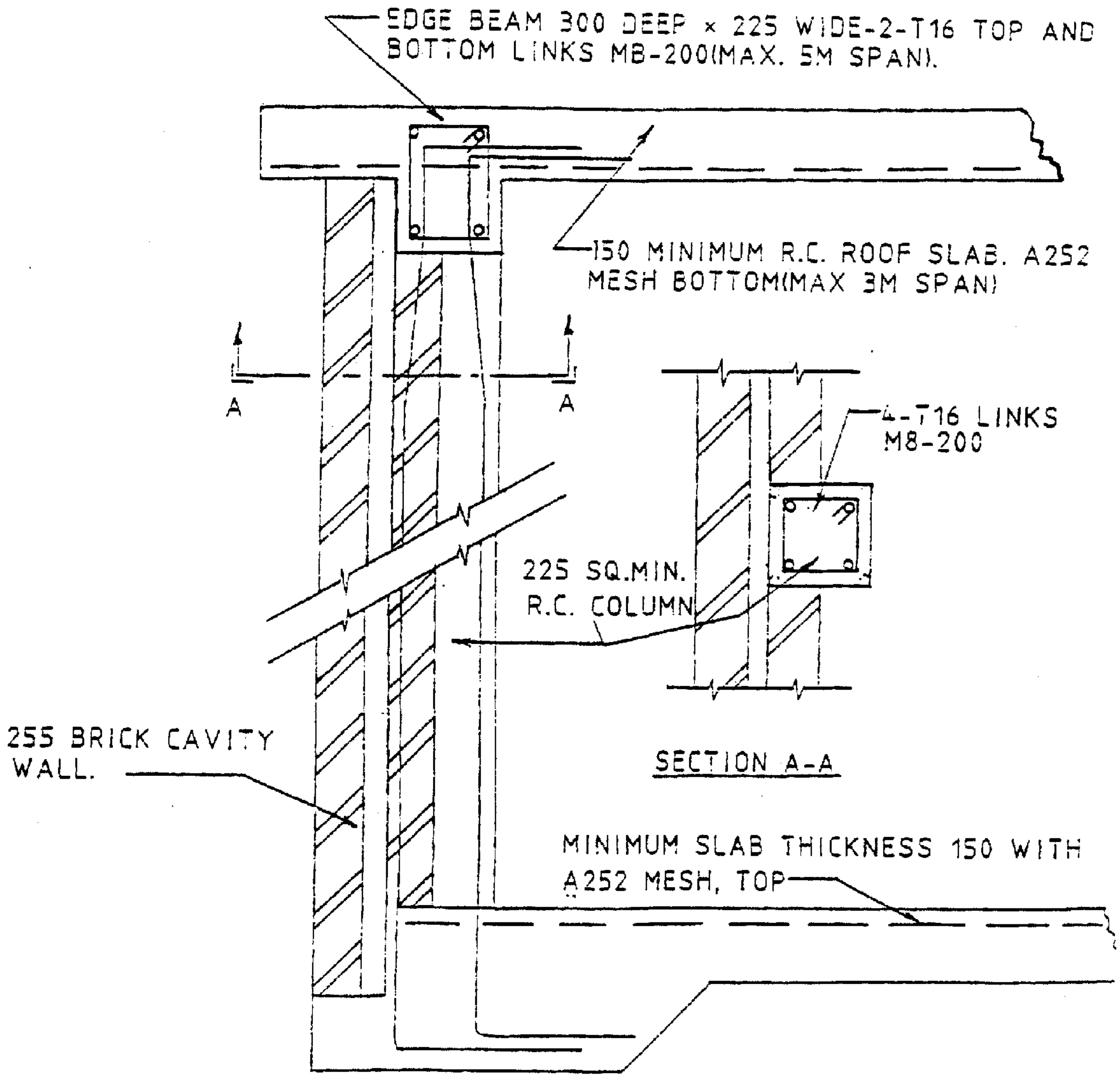

FIGURE B3 - ESH WITH RC COLUMNS

APPENDIX I

MAGAZINE CONSTRUCTION DETAILS

1. Magazines will be constructed to the general dimensions shown in Figures 1 to 3 of the main text and according to the trial program laid out at Table 1.

2. It has been suggested that it may be possible to construct the buildings on rigid bases such that they can be lifted into place as and when required. If portable buildings prove to be impracticable or post test debris cannot be removed then additional test arenas will be needed. Details of the reinforced concrete floor for the portable buildings are to be provided separately if required.

3. Magazines consisting of:

   a. solid brick walls 230 mm thick using English Bond as the bond pattern, or

   b. cavity brick walls 270 mm thick using standard stretcher bond as the bond pattern with standard ties at 450 mm intervals vertically and 900 mm horizontally, the inner wall to be a different colour brick to the outer wall;

are to be constructed in accordance with the trials schedule. Walls shall be provided with a damp proof course laid across the full width of the wall and at least 150 mm above the ground. Damp proof courses will be a membrane type complying with AS 2904.

4. Bricks shall be solid clay building bricks conforming to AS 1225-1984 with a single frog and manufactured to "traditional brick" dimensions (230 mm x 110 mm x 76 mm). The characteristic compressive strength of the bricks will be between 25 MPa and 50 MPa.

5. The mortar used in the construction of the walls will be cement/lime/building sand in the ratio 1:1:6. The mortar constituents will comply with Australian Standards set out in AS 3700.

6. Brickwork must be kept damp for at least 7 days to enable full curing to take place.

7. At least 28 days must be allowed between construction and trial.

8. The concrete roof slab will be 150 mm thick reinforced top and bottom in each direction with mesh reinforcement to achieve a reinforcement ratio of at least 0.175% by cross section area.

APPENDIX II

PRESSURE MEASUREMENT DETAILS

1. For 10 kg tests where the charge will not be placed in the centre of the magazine the following pressure measurement positions are to be monitored:

   a. On the wall closest to the charge, directly opposite the charge.

   b. On the wall closest to the charge, 1 m to the side of gauge a.

   c. Beside and half way up the door.

   d. In the centre of the ceiling

   e. In the centre of the wall to the left of the charge when looking at the wall closest to the charge.

2. For the 25 kg and 50 kg tests where it is intended to place the charge in the centre of the magazine the following pressure measurement positions are to be monitored:

   a. On the wall opposite the door directly opposite the charge.

   b. On the wall to the right of the charge when looking at the door, directly opposite the charge.

   c. In the centre of the ceiling.

   d. Beside and half way up the door.

   e. 150 mm below the ceiling on the centre line of the wall to the right of the charge when looking at the door.

3. Gauges and associated recording equipment must be capable of recording the pressure on the inner surface of the wall as a function of time and integrating the pressure pulse to give the impulse on the wall.

4. An additional pressure gauge will be required outside the magazine, 10 m in front of the door.

5. Based on the results obtained in the initial tests, gauge requirements may be changed for subsequent tests.

APPENDIX III

HIGH SPEED IMAGING DETAILS

1. The object of the video/cine coverage of the events to gather the maximum information on the projection of debris from the walls and roof of the magazine when it is disrupted by the explosion. Ideally, sufficient information should be gleaned from the records to define the complete trajectories of debris including any bounce or roll that may occur after initial impact.

2. Evidence from US work indicates that the debris is projected more or less normal to the surface of the wall or roof at velocities around 100 ms^{-1}.

3. The initial movement of the wall and its breakup are to be recorded and then coverage of the rest of the trajectory should be sufficient to permit debris of half brick size to be resolved. If possible the individual debris picked up in the field should be associated with the data from the video/cine records.

4. A camera is to be positioned to record the initial breakup and movement of the roof.